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R. J. Boyd

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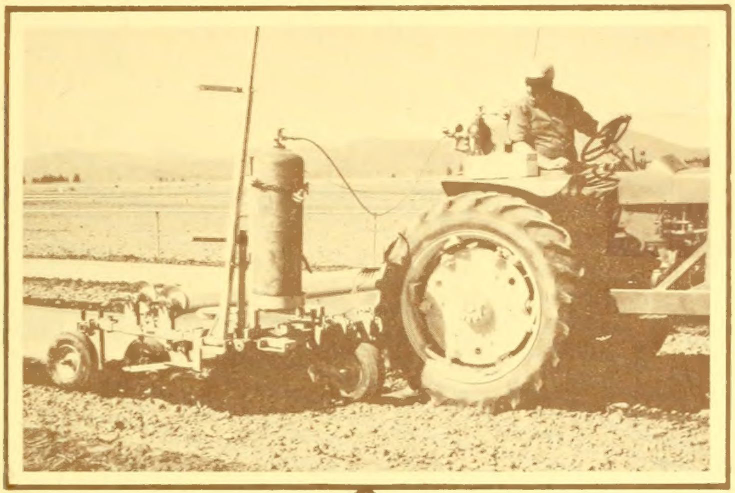

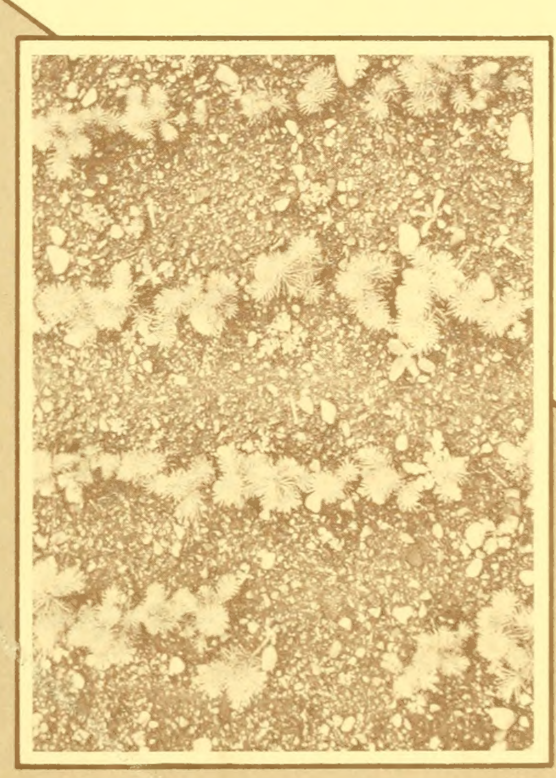

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Abstract

Soil fumigation has improved production of Douglas-fir, western white pine, Engelmann spruce and ponderosa pine stock at two northern Rocky Mountain nurseries. The better fumigation treatments substantially reduced weeds, losses from diseases and insects, and generally resulted in larger stock with improved survival potential. These benefits more than compensated for the cost of fumigation. Fumigation has also resulted in greater operational efficiencies by providing more predictable and more uniform seedling stands. Late summer fumigation with methyl-bromide based fumigants has provided the most dependable overall improvement in nursery operation.

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CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

INTRODUCTION

Research personnel of the Intermountain Forest and Range Experiment Station have been experimenting since 1961 with soil fumigation as a means of improving conifer nursery stock and reducing production costs. These experiments have been in cooperation with nursery personnel of the Northern Region of the USDA Forest Service, the Dow Chemical Company, and Stauffer Chemical Company[1] and were conducted at the Forest Service's Coeur d'Alene nursery, near Coeur d'Alene, Idaho, and at the Savenac nursery, located at Haugen, Montana.

Until 1964 soil fumigation was conducted at the above nurseries on an experimental basis only. By then it was obvious that, in spite of the high cost of fumigation, the benefits generally exceeded the cost by a wide margin. Since 1964, most of the Coeur d'Alene seedbeds have been fumigated on an operational basis prior to the sowing of each conifer crop.

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[1] The assistance of the following personnel is gratefully acknowledged: Nurserymen James W. Augenstein (retired) and Lee L. Mason; Assistant Nurserymen David A. Gibney, Frank Salomonsen, and Steven McDonald; Nursery Technicians Mrs. Bea Fisher and John Isaacson; Mr. Jack Fisher, Dow Chemical Co.; and Mr. Graham Randall, Stauffer Chemical Company.

CONDITIONS, MATERIALS, FUMIGATION METHODS

Soils of the Coeur d'Alene nursery, where most of the trials were conducted, are well-drained sandy loam underlain by water-sorted sands and gravels. Surface-soil pH averages 6.2; organic matter content ranges from 2.6 to 4.2 percent. The site is located at an elevation of 2,500 feet and was previously forested with ponderosa pine (*Pinus ponderosa* Laws.)[2]

Savenac nursery soils involved in fumigation studies are well-drained loams and silt loams derived from stream and glacial outwash deposits. The original vegetation of this site was a mixed conifer type, Douglas-fir [*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco], grand fir [*Abies grandis* (Dougl.) Lindl.], western larch (*Larix occidentalis* Nutt.), and lodgepole pine (*Pinus contorta* Dougl.). Surface soil pH averages 6.6 with an organic matter content of about 2 percent.[2]

After some promising trials of soil fumigation at both Savenac and Coeur d'Alene in 1960, serious experimentation was started at the Coeur d'Alene nursery in the fall of 1961. By 1962, it was obvious that a more complete evaluation was needed. Consequently, in 1963 a major fumigation test was initiated. This included both spring and fall fumigation, a number of additional promising fumigants, varied rates of application for some, and applications at both the Coeur d'Alene and Savenac nurseries (table 1). Soils treated with each fumigant at these two nurseries were broadcast sown with stratified, but otherwise untreated, western white pine (*Pinus monticola* Dougl.), Douglas-fir, ponderosa pine, and Engelmann spruce (*Picea engelmannii* Parry).

Since the 1963 trials, all of the operational fumigation areas have been closely observed, usually with some unfumigated check areas incorporated into the program, to provide continued monitoring of fumigation effectiveness. Additional species have been grown in fumigated soils including grand fir, western larch, and lodgepole pine.

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[2] R. C. McConnell and M. G. Klages. Forest nursery soils of northern Idaho and western Montana. Mont. Agr. Exp. Sta. Bull. 63, 33 p., illus. 1969.

All fumigants were applied according to the manufacturer's recommendation. Fumigants containing methyl bromide (Brozone, Trizone, and MC-33; see table 1, footnote 2) were covered with polyethylene tarpaulins immediately after injection. Vidden-D, M-2441, and M-2467 were injected in the same manner as the methyl bromide-containing fumigants, but were sealed with sprinkler application of water. Most of the Vapam was applied with a gravity-flow dribble applicator, and the soil immediately rototilled, roller-packed, and water-sealed. In the 1963 spring fumigation, the 40-gallon-per-acre rate of Vapam was sealed with polyethylene. All fumigants were applied at soil temperatures above 55°F. with soil moisture near field capacity. In the 1961 fall and 1963 spring trials, each replication contained one unfumigated control plot. Alternate beds were fumigated in the 1963 fall fumigation so that each fumigated bed had an unfumigated check bed adjacent to it. Soil fumigation after 1963 has been on an operational basis with entire "sections" (the area between overhead sprinkler pipes spaced at 50-foot intervals) fumigated and results compared with unfumigated "sections." Either Trizone or a 2:1 mixture of methyl bromide and chloropicrin have been used in these operational-scale fumigations.

Table 1.--*Summary of conditions represented in soil fumigation studies conducted at the Coeur d'Alene (CdA) and Savenac nurseries*

Location	Species sown[1]	Fumigation time	Fumigant[2]						
			Brozone	Trizone	MC-33	Vapam	Vidden-D	M-2441	M-2467
			lb./acre			*gal./acre*			
CdA	WWP,PP	Fall, 1961	170	140	--	--	--	--	--
	DF,ES		340	180	--	--	--	--	--
CdA	GF,DF,	Spring, 1963	110	140	170	[3]40	50	50	50
	PP,ES		170	200	300	80	--	--	--
			340	--	--	--	--	--	--
CdA &	WWP,DF,	Fall, 1963	110	140	170	40	50	50	50
Savenac	PP,ES		170	200	300	80	--	--	--
			340	--	--	--	--	--	--

[1] For the fall 1963 fumigation, all species were sown only in the spring at both nurseries except for western white pine, which was sown both in the spring and the fall at Coeur d'Alene and only in the fall at Savenac. WWP = western white pine; PP = ponderosa pine; DF = Douglas-fir; GF = grand fir; and ES = Engelmann spruce.

[2] Brozone = Methyl bromide (68.6%); Chloropicrin (1.4%); inert (30%) - Dow Chemical Co.
Trizone = Methyl bromide (61%); Chloropicrin (30%);3-Bromopropyne (6.8%) - Dow Chemical Co.
MC-33 = Methyl bromide (66.7%); Chloropicrin (33.3%) - Dow Chemical Co.
Vapam = Sodium N-methyldithiocarbamate - Stauffer Chemical Co.
Vidden-D = 1,3-dichloropropene, 1,2-dichloropropene; 2,3-dichloropropene; 3,3-dichloropropene and related chlorinated hydrocarbons (100%) - Dow Chemical Co.
M-2441 = Vidden-D (80%); Chloropicrin (20%) - Dow Chemical Co.
M-2467 = Vidden-D (90%); 3-bromopropyne (10%) - Dow Chemical Co.

[3] Sealed with polyethylene tarp; all other Vapam treatments water sealed.

WEED CONTROL

METHODS

The effects of fumigation on weed control have been evaluated by periodic sample counts of weeds on three or four randomly selected 1-square-foot plots during the first growing season and the early part of the second. Weed counts were followed by hand weeding. When possible, time studies of hand weedings were conducted to relate labor cost to weed density. Greenhouse germination of weeds from soil samples taken at various soil depths provided information on the residual weed-seed population and its control by fumigation. Experimental design and statistical analyses were obtained by standard randomized block layouts and analysis of variance, by paired-sample t-test procedures, or by regression analysis.

EFFECTS ON WEED POPULATIONS

Weed control has been an outstanding, readily visible feature of the benefits of soil fumigation (figure 1). Most of the fumigants consistently resulted in substantial reductions in subsequent weed populations; this was especially apparent during the early part of the first growing season following fumigation (table 2). Fumigants that did not show a positive control of weeds were: (1) Vapam applied 40 gallons per acre and not covered by tarpaulins; (2) Brozone applied 110 pounds per acre; and (3) Vidden-D applied 50 gallons per acre.

In general, those products containing 1,3 dichloropropene and related hydrocarbons (Vidden-D, M-2441, and M-2467) were not as effective in controlling weeds as were the methyl bromide-based fumigants or Vapam. In the 1963 spring fumigation, which was less influenced by a post-fumigation influx of windblown weed seed than any of the fall fumigations, weed control was roughly proportional to the amount of methyl bromide and 3-Bromopropyne (propargyl bromide) in the fumigant. Vapam applied at 40 gallons per acre and sealed with a polyethylene tarpaulin was as effective as the water-sealed material at twice this application rate.

Periodic weed counts showed that the effects of fumigation on weed populations tended to diminish during the summer. By September 1963, there were no significant differences in weed population which could be attributed to fumigation; nor was there any carry-over effect into the second growing season. Apparently weeds germinating on the treated plots in late summer and the following spring originated from windborne seed.

Table 2.--*Effects of soil fumigation on weed density, Coeur d'Alene and Savenac nursery soil fumigation trials, 1961-1963*

Trial	Fumigant (amount applied/acre)	Weeds per square foot[1]
1961 (Fall)[2]	Brozone (170 lb.)	1
Coeur d'Alene	Brozone (340 lb.)	2
(counted 6/25/62)	Trizone (140 lb.)	10
	Trizone (180 lb.)	11
	Unfumigated	20
1963 (Spring)	Vapam (40 gal.)	3
Coeur d'Alene	Brozone (340 lb.)	4
(average of four	MC-33 (300 lb.)	5
counts during 1963	Vapam (80 gal.)	5
growing season)	Brozone (170 lb.)	7
	Trizone (200 lb.)	7
	M-2467 (50 gal.)	8
	MC-33 (170 lb.)	10
	Trizone (140 lb.)	11
	Vidden-D (50 gal.)	13
	M-2441 (50 gal.)	14
	Brozone (110 lb.)	17
	Unfumigated	22
1963 (Fall)	Trizone (200 lb.)	8
Coeur d'Alene	Brozone (170 lb.)	8
(counted 6/24/64)	MC-33 (170 lb.)	8
	Brozone (340 lb.)	14
	Vapam (80 gal.)	14
	M-2467 (50 gal.)	15
	Vidden-D (50 gal.)	16
	Trizone (140 lb.)	17
	M-2441 (50 gal.)	18
	MC-33 (300 lb.)	21
	Brozone (110 lb.)	22
	Vapam (40 gal.)	34
	Unfumigated	37
1963 (Fall)	Brozone (170 lb.)	5
Savenac	Brozone (340 lb.)	8
(counted 6/17/64)	Trizone (200 lb.)	11
	Vapam (80 gal.)	11
	MC-33 (170 lb.)	12
	MC-33 (300 lb.)	14
	M-2467 (50 gal.)	26
	Trizone (140 lb.)	27
	M-2441 (50 gal.)	30
	Vidden-D (50 gal.)	44
	Brozone (110 lb.)	45
	Vapam (40 gal.)	66
	Unfumigated	80

---

[1] Vertical lines indicate those population estimates that are not significantly different at the 95% probability level.

[2] No statistical test made.

There was some long-range weed control resulting from a single fumigation. Following the 1963 fall fumigation, soil samples were taken in selected plots, both fumigated and unfumigated, to a depth of 6 inches. The surface inch of soil was discarded to eliminate weed seed which had blown in since fumigation. Samples of the remainder of the soil were then spread on containers in the greenhouse, and weeds counted as they germinated. A total of only six weeds germinated on 37 samples of fumigated soils; in contrast, 33 samples from unfumigated soils supported a total of 425 weeds. Fumigation virtually eliminated viable residual weed seed to a depth of at least 6 inches. Many of these weed seeds have a prolonged viability and might eventually be brought to the surface by cultivation where they could germinate; thus, the treatments should provide some long-range weed control benefits.

A similar test of weed control was made in the fall of 1965 comparing soils operationally fumigated with Trizone at 200 pounds per acre with unfumigated soils. Soil samples were collected on October 10 after an early September fumigation. The soil had not been disturbed in the period between fumigation and sampling. Twenty-four randomly selected locations were chosen in both fumigated and unfumigated areas. At each location a sample was obtained from each of three levels beneath the soil surface: 1 to 2 inches; 4 to 5 inches; and 8 to 9 inches. Weeds were then germinated from measured subsamples in the greenhouse with the following results:

Soil depth	*Number of weeds per sample*	
(Inches)	*Fumigated*	*Unfumigated*
1 - 2	6.9	44.9
4 - 5	7.4	46.0
8 - 9	5.4	29.6

Differences in weed population between fumigated and unfumigated soils were highly significant (99% probability level).

The deep-action effect of fumigation on residual weed seeds, as demonstrated in these two tests, promises to provide a reduction in weed population for future crops.

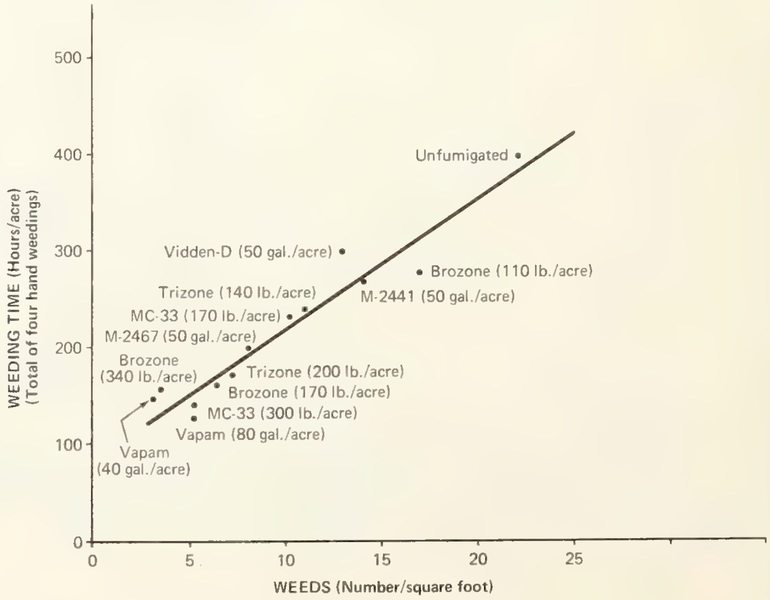

Figure 1.--Weeding time as related to the weed densities resulting from various fumigant treatments in the 1963 spring trials at Coeur d'Alene nursery.

None of the fumigation treatments tested have eliminated weeds. Some hand weeding has been required to control deep-rooted perennials, weeds from windblown seed, and, no doubt, weed seed which escaped fumigation due to imperfect application techniques. Much of the effort spent in fumigation can be lost if weeds, which become established in spite of the best fumigation efforts, are not removed or killed prior to their seed maturation and dispersal.

EFFECTS ON WEED CONTROL COSTS

Hand-weeding time studies were made during the 1963 spring and fall fumigation trials at Coeur d'Alene. A range of weed densities provided by fumigation treatments were correlated with weeding time and cost. Figure 1 shows the relationship between number of weeds, weeding time, and fumigant treatment for a total of four hand weedings during the first growing season in the 1963 spring fumigation trials. Unfumigated beds with approximately 22 weeds per square foot required nearly 400 hours of hand-weeding time per acre; weeding time was below 300 hours per acre on fumigated beds. The better fumigants reduced weed populations to less than 10 weeds per square foot and weeding times to under 200 hours per acre.

For seedbeds fumigated in the fall of 1963, time records were obtained for a single hand weeding in late June of the following year (figure 2). Weeding time for given weed densities ran higher than those for spring fumigation because the weeds were larger and greater care had to be used in removing them to keep from damaging tree seedlings. Unfumigated beds, and those fumigated with Brozone at 110 pounds per acre and Vapam at 40 gallons per acre (not covered by tarpaulins), had two to three times as many weeds as the more effective fumigants. Weed populations were generally higher in this test than in the 1963 spring tests due to the accumulation of windborne seed during the fall and winter following fumigation.

These two analyses (figures 1 and 2) indicate that, on the average, 10 fewer weeds per square foot should result in a reduction of 137 to 155 hours per acre in weeding

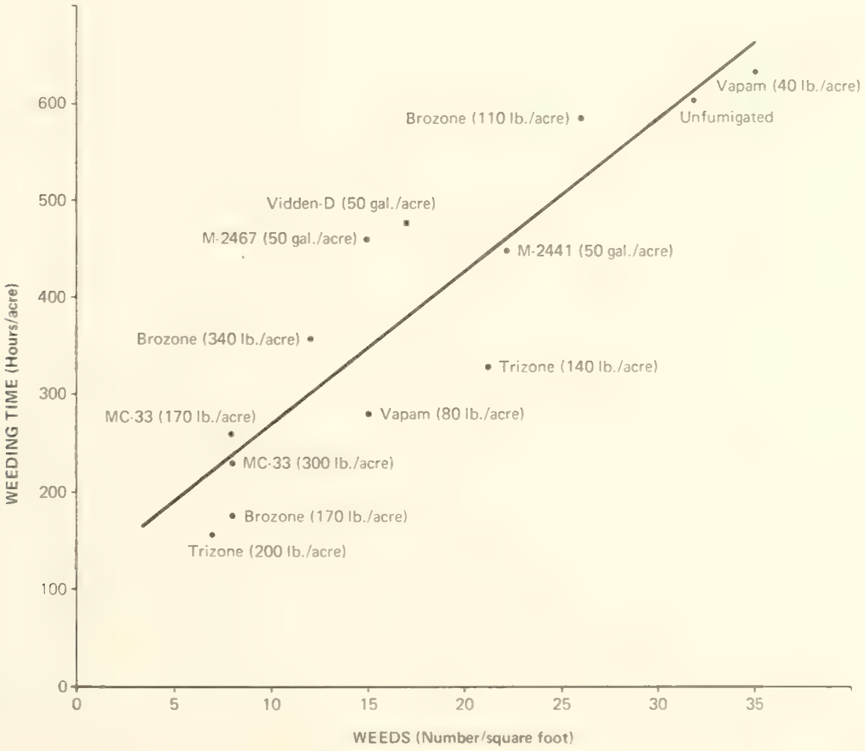

Figure 2.--Weeding time and weed density relationships, 1963 fall fumigation (four blocks, June 24 hand weeding).

time within the density ranges sampled. At a labor cost of $2.50 per hour, this would represent a savings of $342 to $387 per acre. For the more effective fumigants, which reduced weeds by over 20 per square foot, the savings in labor were generally over $700 per acre and ranged as high as $1,000 per acre.

Hand weeding is not, however, the only alternative to weed control. Herbicides, including the aromatic oils, and mechanical cultivation are successfully used at many nurseries to reduce weed populations and minimize hand work. Aromatic oils are successfully used on most species at Savenac, but have never been a dependable weed control measure at Coeur d'Alene without the risk of damage to the conifer crop. As yet, none of the synthetic herbicides has been useful except on non-crop areas such as fence lines and irrigation pipelines. Mechanical cultivation between drill rows has been abandoned because of the danger of soil splash on small seedlings. However, fumigation as a weed control measure alone is financially justified at Coeur d'Alene where conditions are characterized by: high residual weed seed population; weeds resistant to selective herbicides; crop species for which there is no suitable selective herbicide; and soil conditions which prevent mechanical cultivation.

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1971. Effects of soil fumigation on production of conifer nursery stock at two northern Rocky Mountain nurseries, USDA Forest Serv. Res. Pap. INT-91, 19 p., illus.

Soil fumigation has improved production of Douglas-fir, western white pine, Engelmann spruce and ponderosa pine stock at two northern Rocky Mountain nurseries. The better fumigation treatments substantially reduced weeds, losses from diseases and insects, and generally resulted in larger stock with improved survival potential. These benefits more than compensated for the cost of fumigation. Fumigation has also resulted in greater operational efficiencies by providing more predictable and more uniform seedling stands.

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DISEASE CONTROL

METHODS

Sample plots sown with known numbers of seed, nursery inventory data, and periodic counts of dead and dying seedlings were used to evaluate the effects of soil fumigation on the control of seedling diseases. Differences in germination and seedling survival were judged to be caused primarily by treatment effects on pathogenic fungi, but effects on nematodes and insects may have contributed to these differences. Plot design and statistical analysis used in the disease control evaluation were the same as those used in evaluating weed control.

EFFECTS ON SEEDLING PRODUCTION

In the 1961 tests, fumigated seedbeds had from 20 to 150 percent more seedlings than unfumigated beds, based on a September inventory of the 1-0 stock. Average increases were greatest for Douglas-fir (66%), followed by western white pine (57%), Engelmann spruce (39%), and ponderosa pine (32%). Germination and post-emergence mortality patterns indicate that fumigation reduced pre- and post-emergence mortality about equally well in Douglas-fir, ponderosa pine, and Engelmann spruce. Western white pine stand increases in fumigated soils, however, must be attributed largely to control of pre-emergence mortality since post-emergence mortality was greatest in the fumigated beds. Brozone applied at 340 pounds per acre produced the greatest average yield increase (98%), followed by Trizone at 180 pounds per acre (48%), Trizone at 140 pounds per acre (32%), and Brozone at 170 pounds per acre (17%).

A number of the 1963 fall fumigation treatments at Coeur d'Alene provided substantial and significant increases in seedling production of 2-0 stock (table 3). The production of western white pine was significantly increased by all of the methyl bromide-based fumigants, except the lowest rates of Trizone and Brozone, and by both application rates of Vapam. Increases in the 2-0 seedling stand, for effective treatments, ranged from 50 to 97 percent, with Trizone at 200 pounds per acre providing the largest increase.

Douglas-fir production results were similar except that neither the highest rate of Brozone (340 lb./acre) nor the 40 gallon per acre Vapam treatments were effective in increasing production. The effective treatments provided increases in Douglas-fir production of 23 to 144 percent. MC-33 at 300 pounds per acre was outstanding with a 144 percent increase in the 2-0 stand.

Engelmann spruce production was increased significantly by two fumigants (Trizone at 140 lb./acre and Brozone at 170 lb./acre). Other production gains probably were present although they are not statistically significant. Replications may have been inadequate to remove the effect of the great variability in disease incidence in the nursery fields. Percentage increases in spruce production ranged from 115 to 133 percent.

Table 3.--*Differences in density per square foot of 2-0 stock grown in fumigated and unfumigated seedbeds at Coeur d'Alene nursery, 1963 fall fumigation*

Fumigant (amount applied/acre)		Western white pine			Douglas-fir			Engelmann spruce			Ponderosa pine		
		Fum.	Unfum.	Diff.	Fum.	Unfum.	Diff.	Fum.	Unfum.	Diff.	Fum.	Unfum.	Diff.
		Seedling density per square foot											
Trizone	(140 lb.)	38	30	8	34	32	2	43	20	23*	60	52	8
	(200 lb.)	45	23	22**	39	26	13*	30	23	7	60	51	9
Brozone	(110 lb.)	36	29	7	29	19	10	29	13	16	52	57	-5
	(170 lb.)	48	29	19*	58	47	11*	42	18	24*	66	60	6
	(340 lb.)	42	28	14*	47	49	-2	24	21	3	54	51	3
MC-33	(170 lb.)	39	26	13*	47	32	15*	20	7	13	58	51	7
	(300 lb.)	52	32	20*	39	16	23**	39	25	14	52	54	-2
Vidden-D	(50 gal.)	29	18	11	20	20	0	22	22	0	57	58	-1
M-2441	(50 gal.)	32	31	1	27	28	-1	21	19	2	45	53	-8
M-2467	(50 gal.)	30	21	9	27	29	-2	16	23	7	60	51	9
Vapam	(40 gal.)	46	28	18*	34	35	-1	13	9	4	51	48	3
	(80 gal.)	43	25	18*	39	19	20*	29	28	1	46	33	13*

*Differences significant at 95% probability level.
**Differences significant at 99% probability level.

Ponderosa pine production was, in general, the least affected by fumigation. Only Vapam at 80 gallons per acre provided a significant increase (39%) in 2-0 seedling production. None of the dichloropropene base compounds (Vidden-D, M-2441, or M-2467), nor the lowest rate of Brozone, resulted in any significant changes in plant production.

In seedbeds fumigated in the fall of 1963, the post-emergence mortality during the first growing season was generally only slightly greater in unfumigated than in fumigated seedbeds. Also, the magnitude of differences in the 1-0 stands in fumigated and unfumigated beds was about the same as the 2-0 stand differences. Thus the treatment effects on overall plant production seem to have been primarily the result of reductions in pre-emergence losses.

The effects of fumigation on the ultimate production, and therefore, by inference, on the incidence of disease losses, were highly variable with significant block effects as well as significant treatment effects. A particular treatment tended to look effective or ineffective depending on whether it happened to fall in an area of high disease incidence and virulence or in an area where conditions were naturally unfavorable for the pathogen. The design of the trials was generally not adequate to remove the effect of such differences and provide good statistical information on the relative effectiveness of the various fumigants.

The effects of the 1963 fall fumigation at the Savenac nursery were similar to those at Coeur d'Alene. Production of 3-0 Engelmann spruce stock was increased from 21 to 35 percent by MC-33 at 300 pounds per acre, Trizone at 200 pounds per acre, and Brozone at 170 pounds per acre. Although sampling of other species was not sufficient for a good statistical test, it was obvious that western white pine production was greatly benefited by MC-33 at both rates, Trizone at 200 pounds per acre and by Vapam. Savenac ponderosa pine was least benefited by fumigation but did display increases in production with the better fumigants such as Trizone at 200 pounds per acre.

Spring fumigation, unlike the fall fumigations, provided no detectable control of disease losses. Neither post-emergence damping-off nor the 1-0 stand densities were significantly different on fumigated and unfumigated soils. In fact, seedlings growing in fumigated soils were often stunted and chlorotic. If fumigation provided some disease control, it was masked either by fumigant toxicity or unknown secondary detrimental effects. While there may be some advantage to sowing as soon after fumigation as possible, Coeur d'Alene spring weather is generally not warm enough to bring the soil temperature up to suitable fumigation levels until mid-May, which is generally several weeks beyond the optimum sowing date. This delay in sowing, plus the additional delay imposed by allowing time for the chemicals to dissipate from the soil, makes spring fumigation impractical.

SEED COST SAVINGS

The higher seedling survival promoted in the nursery beds by fumigation can result in appreciable savings through lower seed costs. The amount of savings depends not only on the effectiveness of disease and insect control, but also upon the desired seedbed density and upon seed costs.

Using a final density goal of 40 seedlings per square foot, savings in seed cost have ranged as high as $1,100 per acre for a fumigation investment of approximately $400 per acre. This occurred in Douglas-fir seedbeds at Coeur d'Alene which have been particularly subject to disease losses. Seed cost savings have been highest with Douglas-fir, western white pine, and ponderosa pine. Savings with Engelmann spruce and western larch have been relatively small due to the low cost per unit count of seed.

SEEDLING GROWTH

METHODS

The effects of soil fumigation on seedling development have been evaluated by observation and by measurement of the following characteristics on three to four randomly selected groups of 10 seedlings from both fumigated seedbeds and their paired, unfumigated controls:

Height of shoot
Weight of shoot (ovendry basis)
Stem diameter (at root collar)
Shoot-root ratio (by weight)
Weight of roots (ovendry basis)
Root area index[3]

Most of the results are based on the 1963 fall fumigation trials at Coeur d'Alene and Savenac. Only those fumigation treatments which seemed to have provided the most effective pest control and the best growth responses were included in the sample measurements.

EFFECTS ON SEEDLING SIZE

Soil fumigation at Savenac and Coeur d'Alene has caused a variety of seedling growth responses ranging from a definite depression of growth to substantial increases in seedling size. In the 1963 spring fumigation, for instance, a number of treatments caused reduced growth and seedling chlorosis. There were no obvious increases in seedling growth resulting from spring fumigation.

In the 1963 fall-fumigation trials, measured seedlings provide results ranging from "no-effect" to substantial and significant increases in the size characteristics of 2-0 and 3-0 seedlings (figure 3 and table 4). In general, seedlings grown in fumigated soils were larger than those from unfumigated soil. In about 22 percent of the individual comparisons which were made, this difference proved significant at the 95-percent level of probability or greater. There were not enough differences in the

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[3] A technique (similar to the "root titration" measurement used by many nursery workers) in which the relative surface areas of root systems are determined by dipping the roots in a dilute water-india ink suspension, draining, washing the roots in water, and colorimetrically measuring the amount of ink transferred. The recorded difference in light transmittance is the "root area index."

Table 4.--*Effect of soil fumigation on size attributes of 2-0 stock grown at Coeur d'Alene and Savenac nurseries, 1963 fall fumigation*

Nursery & treatment (amount applied/acre)	Top height			Stem diameter			Root area index			Top weight[1]			Root weight[1]			Shoot/root ratio[2]		
	Fum.	Unfum.	Diff.	Fum.	Unfum.	Diff.	Fum.	Unfum.	Diff.	Fum.	Unfum.	Diff.	Fum.	Unfum.	Diff.	Fum.	Unfum.	Diff.
		cm.			*mm.*						*g.*			*g.*				
WESTERN WHITE PINE																		
Coeur d'Alene																		
Trizone (200 lb.)	7.5	5.7	1.8	2.6	2.5	0.1	8.4	7.8	0.6	0.88	0.72	0.16	0.37	0.42	-0.05	2.35	1.71	0.64
MC-33 (300 lb.)	10.3	6.2	4.1*	3.3	2.6	.7*	13.2	10.9	2.3	1.62	.81	.81*	.58	.48	.10	3.03	1.70	1.33*
Vapam (80 gal.)	6.7	6.6	.1	2.3	2.3	.0	8.3	13.1	-4.8**	.67	.77	-.10	.35	.53	-.18	1.95	1.45	.50
Savenac																		
Trizone (200 lb.)	7.7	5.6	2.1	2.4	2.1	.3*	6.2	4.6	1.6	.74	.48	.26	.29	.23	.06	2.60	2.08	.52
MC-33 (300 lb.)	6.6	5.5	1.1	2.0	1.9	.1	4.8	4.9	-.1	.53	.42	.11	.25	.22	.03	2.32	2.00	.32
Brozone (340 lb.)	5.8	4.0	1.8*	2.2	1.8	.4*	5.6	3.5	2.1*	.59	.34	.25*	.28	.18	.10*	2.14	1.92	.22**
Vapam (80 gal.)	6.1	4.8	1.3	2.1	2.0	.1	4.8	4.3	.5	.51	.38	.13	.22	.22	.00	2.43	1.77	.66**
DOUGLAS-FIR																		
Coeur d'Alene																		
Trizone (200 lb.)	9.8	7.8	2.0**	2.9	2.4	.5*	7.9	4.7	3.2**	1.08	.60	.48**	.46	.29	.17**	2.35	2.03	.32**
MC-33 (300 lb.)	9.0	6.9	2.1*	2.4	2.3	.1*	8.0	7.0	1.0	.81	.55	.26	.33	.32	.01	2.40	1.72	.68**
Brozone (170 lb.)	11.0	10.8	.2	3.0	2.9	.1	12.2	11.9	.3	1.16	1.15	.01	.54	.48	.06	2.21	2.46	-.25
ENGELMANN SPRUCE																		
Coeur d'Alene																		
Trizone (200 lb.)	8.9	8.1	.8	3.2	2.9	.3	10.8	10.3	.5	1.35	1.25	.10	.51	.47	.04	2.69	2.65	.04
Savenac[3]																		
Trizone (200 lb.)	13.7	8.9	4.8**	2.9	2.6	.3**	--	--	--	1.24	.88	.36*	.42	.45	-.03	2.98	1.90	1.08**
MC-33 (300 lb.)	16.6	9.0	7.6*	3.6	2.8	.8	--	--	--	2.22	.98	1.24	.68	.44	.24	3.26	2.19	1.07
Brozone (170 lb.)	14.5	9.5	5.0*	3.4	2.7	.7	--	--	--	1.63	.80	.83*	.52	.38	.15	3.11	2.26	.85
PONDEROSA PINE																		
Coeur d'Alene																		
Trizone (200 lb.)	22.1	22.0	.1	3.1	3.2	-.1	9.6	10.5	-.9	2.17	2.09	.08	.61	.67	-.06	3.57	3.14	.43
MC-33 (300 lb.)	21.9	23.6	-1.7	2.9	3.6	-.7	8.7	12.5	-3.8	1.82	2.66	-.84	.50	.78	-.28	3.73	3.47	.26
Brozone (340 lb.)	22.7	22.2	.5	3.2	3.2	.0	8.9	8.8	.1	1.97	2.04	-.07	.58	.57	.01	3.56	3.61	-.05
Savenac																		
Trizone (200 lb.)	22.4	20.7	1.7	3.0	3.0	.0	8.2	6.3	1.9	1.87	1.78	.09	.36	.38	-.02	5.26	4.61	.65
MC-33 (300 lb.)	20.2	18.6	1.6**	2.8	2.5	.3	8.6	7.6	1.0	1.38	1.05	.32**	.36	.32	.04*	3.80	3.24	.56**
Brozone (170 lb.)	18.7	18.0	.7	2.5	2.3	.2	10.1	7.3	2.7*	1.00	.85	.15**	.35	.30	.05	2.93	2.81	.12

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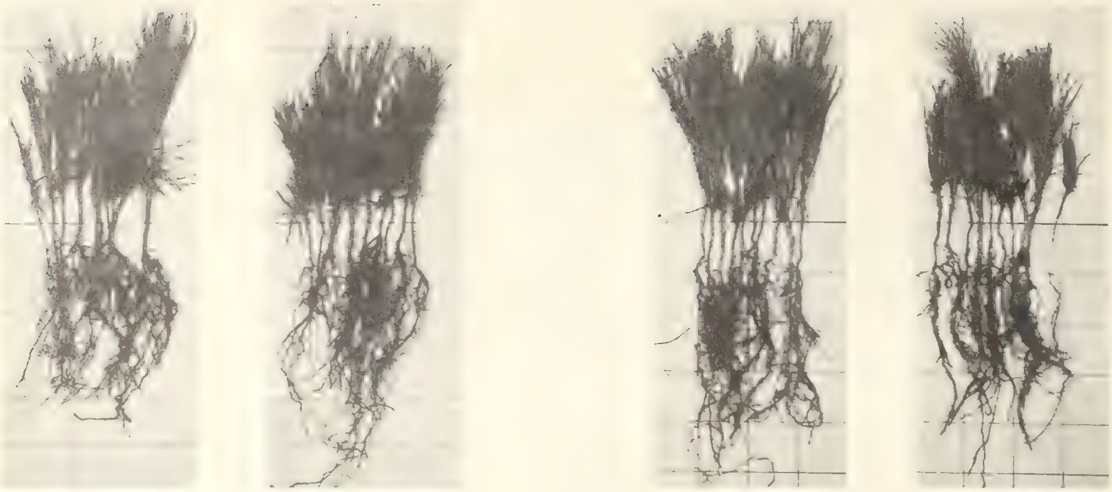
[1] Ovendry basis.

[2] Shoot/root ratio computed from ovendry weights of tops and roots. Each sample = 10 trees.

[3] Engelmann spruce at Savenac nursery was measured as 3-0 stock.

*Differences significant at 95% probability level.

**Differences significant at 99% probability level.

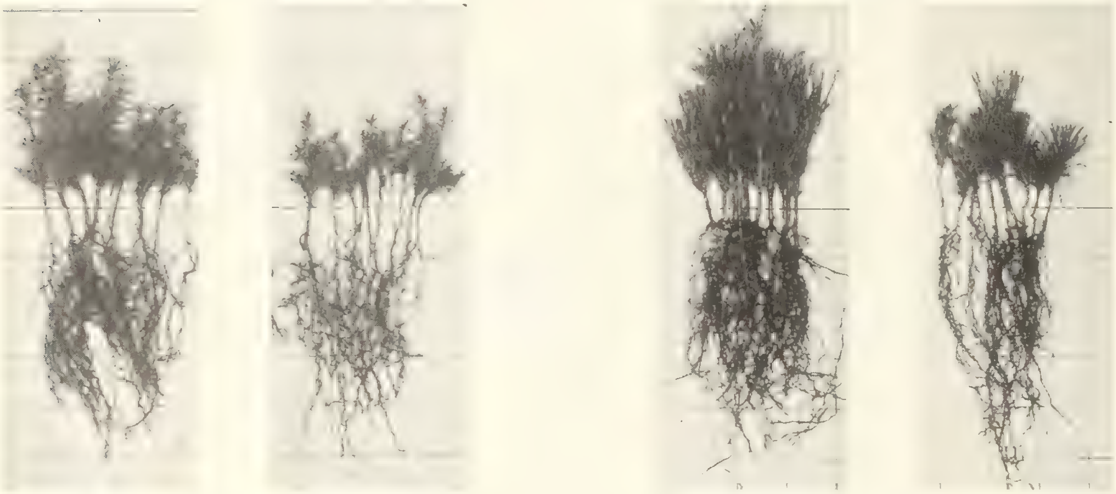


Fumigated Unfumigated

Ponderosa pine (2-0)
Coeur d' Alene nursery

Fumigated Unfumigated

Ponderosa pine (2-0)
Savenac nursery

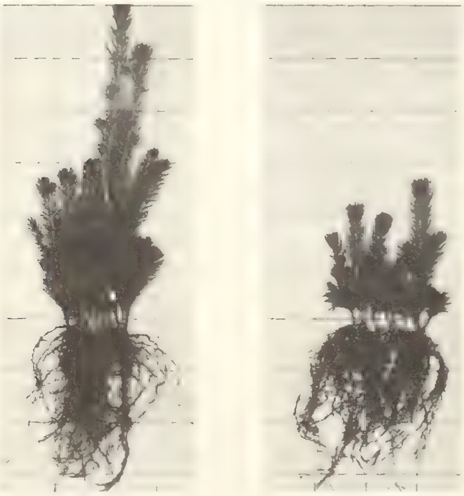


Fumigated Unfumigated

Douglas-fir (2-0)
Coeur d' Alene nursery

Fumigated Unfumigated

Western white pine (2-0)
Coeur d' Alene nursery



Fumigated Unfumigated

Engelmann spruce (3-0)
Savenac nursery

Figure 3. — Some representative samples of the effects of soil fumigation with MC-33 at 300 pounds per acre on the size of conifers grown at Coeur d'Alene and Savenac nurseries. (Background grid = 2-inch squares.)

effects of individual fumigants to warrant a preference for any of the methyl bromide-based formulations. The effects of Vapam were measured only on western white pine and are inconclusive. None of the fumigants caused any significant changes in the measured characteristics of ponderosa pine at Coeur d'Alene. Douglas-fir had the largest proportion of significant increases of seedling size, followed by spruce, western white pine, and ponderosa pine.

Most of the estimates of the effect of fumigation on seedling size are probably conservative since the higher densities, typical of most fumigated seedbeds, tended to independently reduce most seedling size characteristics. The growth of western white pine seedlings at Savenac in thinned and unthinned beds demonstrates these relationships (table 5). Although fumigation generally resulted in larger stock at both high and low densities, the high-density seedlings grown in fumigated soil were

Table 5.--*Size characteristics of 2-0 western white pine seedlings grown at low (55/sq.ft.) and high (153/sq.ft.) seedbed densities in fumigated and unfumigated soil*

Characteristic	Seedbed density	Fumigated[1]		Unfumigated[1]
Top height (cm.)	Low	6.0	**	4.9
		--	**	**
	High	7.1	**	5.0
Stem diameter (mm.)	Low	2.4	**	2.2
		**	*	**
	High	1.9	*	1.7
Root-area index (units)	Low	7.1	*	5.5
		**	*	**
	High	3.5	--	3.2
Top dry weight (g.)	Low	0.93	**	0.50
		**	--	**
	High	0.45	**	0.31
Root dry weight (g.)	Low	0.35	**	0.28
		**	**	**
	High	0.17	--	0.15
Shoot/root ratio (dry weight basis)	Low	2.08	*	1.82
		*	**	*
	High	2.66	**	2.06

[1] Asterisks between any horizontal or vertical pair of the four means given for each characteristic indicate a significant difference at the 95% (*) or 99% (**) probability level. Dashed lines (--) indicate no significance. Symbols within the diagonal lines mean that the test applies only to the means connected by the diagonal line.

generally smaller than seedlings grown at low density in unfumigated soil. Thus, in this extreme case, the density effects have completely concealed the true fumigation effects. If all of the size comparisons could have been made at common densities, both the magnitude and number of significant differences in seedling size would probably have been greater.

In general, the increases in seedling size characteristics associated with soil fumigation can be considered beneficial. Seedlings grown in fumigated soil are generally large enough to outplant at an earlier age than those from unfumigated soils. Even ponderosa pine, which showed no increase in size in the 1963 fall-fumigation tests at Coeur d'Alene, has responded to subsequent operational fumigation with improved growth and a higher percentage of trees developing fascicled needles during the first growing season. This improved growth has permitted the shipment of 1-0 ponderosa pine stock. Production time for Engelmann spruce stock has been shortened by 1 year, and some 1-0 Douglas-fir may be plantable. A 1-year reduction in time to produce seedling stock is equivalent to a cost savings of $3 to $4 per thousand or $3,000 to $4,000 per acre.

In one respect, however, the increased seedling growth may be detrimental. Seedlings from fumigated soils consistently have higher shoot-root ratios than those from unfumigated soil (table 4), indicating a poor "balance" of tops to roots. This has resulted not from a decrease in root weight, but rather from a proportionately greater increase in top weight than root weight. It seems that this effect may be, at least partially, an artifact resulting from standard lifting depth and root-pruning lengths, regardless of seedling size. Just how high the shoot-root ratio can go before it reduces field survival and growth is not known. To limit the development of high ratios in fumigated soils, nurserymen might wish to place greater emphasis on cultural practices such as root pruning in place or "root wrenching."

The reasons for improved seedling growth in fumigated soils are not clear. It is unlikely that the improvement can be attributed to reduced weed competition since both fumigated and unfumigated beds were kept relatively weed free. Reduced populations of soil organisms may have resulted in better nutrition of seedlings--or in a reduction of sublethal infections which could reduce growth without killing the seedlings.

OUTPLANTING
SURVIVAL

METHODS

The survival potential of nursery stock grown in fumigated soil has been tested by a nursery-based "moisture-stress-plot" procedure rather than by field planting tests.[4] Stock (2-0) from the 1963 fall-fumigated test was used in this phase of the work. Seedlings from the same treatments used in the evaluation of growth (those shown in table 4) and from adjacent unfumigated beds were lifted in late April of 1966, stored until late May, and planted in the moisture-stress plots. All test seedlings were kept well-watered until July 1. The seedlings were then subjected to three moisture-stress regimes during the remainder of the growing season. Three random samples of 24 seedlings were tested for each species-fumigant-moisture stress combination. Survival was determined at 2-week intervals during the first growing season.

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[4] Raymond J. Boyd and others. Moisture-stress-plot evaluation of nursery stock survival and growth potential. Western Forest Nursery Counc. Proc. 1968: 34-39, illus.

EFFECTS ON SURVIVAL

Except for the Coeur d'Alene ponderosa pine, and western white pine grown at very high densities, soil fumigation seems to have increased the survival potential of the stock (table 6). Differences were not great and the results were quite variable. Particularly notable were the 9 and 16 percent average increases in survival of Douglas-fir grown in fumigated soils and tested under severe and moderate moisture-stress levels, respectively. Fumigation significantly reduced the survival potential of ponderosa pine grown at Coeur d'Alene and tested at the moderate moisture stress level. In western white pine, both at Coeur d'Alene and at Savenac, there was no significant effect of fumigation on survival potential at any moisture stress level.

Although there is evidence that fumigation may reduce the survival potential of 2-0 ponderosa, this may not be a problem under the current practice of planting 1-0 rather than 2-0 stock. Fumigation, by stimulating early growth, may bring about severe competition at an earlier age. Thus 2-0 stock grown in fumigated soil may be suffering from rather severe competition which could be reflected in reduced survival capabilities. In contrast, the 1-0 stock is still relatively free growing in the nursery beds. Some recent field tests show that there is very little, if any, difference in field survival of 1-0 and 2-0 ponderosa pine grown in fumigated nursery soils.

Table 6.--*Effects of moisture stress on survival of outplanted 2-0 stock grown in fumigated and unfumigated soils*

Nursery and species	Low stress			Moderate stress			Severe stress		
	Fum.	Unfum.	Diff.	Fum.	Unfum.	Diff.	Fum.	Unfum.	Diff.
	Percent survival[1]								
Coeur d'Alene									
Ponderosa pine	96	97	-1	86	92	-6*	60	70	-10
Douglas-fir	92	89	3	71	55	16*	46	35	9*
Western white pine	94	97	-3	92	91	1	0	1	-1
Savenac									
Ponderosa pine	96	96	0	95	86	9	62	53	9
Western white pine									
Low density[2]	96	94	2	97	89	8	1	0	1
High density[2]	83	93	-10	81	84	-3	0	0	0

[1] Percent of survival converted to arcsin $\sqrt{\%\ \text{survival}}$ for statistical analysis.
[2] From fumigation-seedbed-density interaction study (see table 5).
*Differences significant at 95% probability level.

DISCUSSION, CONCLUSIONS

Several years of trials have demonstrated that soil fumigation at the Coeur d'Alene and Savenac nurseries is a practical operation from the standpoint of pest control, growth stimulation, and increased survival potential.

Weed and disease control have been best with methyl bromide-based fumigants and with Vapam, applied at medium to high rates. The dichloropropene-based fumigants were not effective enough to be considered practical. Late August or early September fumigation has proven more effective and more practical than spring fumigation. Fumigation at this time of year gives plenty of time to prepare the soil and to fumigate at the optimum temperature and moisture content. The nursery workload is relatively low at this time, so the extra job of fumigation is not a great hardship to the nurseryman. Most important, however, when conditions for sowing are favorable the following spring, the soil can be worked and the seed sown at the earliest possible date to gain the advantage of early germination and a long growing season. Spring fumigation proved operationally difficult and resulted in stunted seedlings and no observable disease control.

Both spring and fall fumigation substantially reduced weed populations during the first growing season, and reduced potential weeds by killing seed to a depth of at least 9 inches. When compared to hand weeding, the more effective fumigants provided substantial savings in weed control costs.

Production was greater in effectively fumigated seedbeds, reflecting primarily the control of pathogenic fungi. Control of white grubs was observed 1 year and may have played a part in the observed effects in other years. Although nematodes were not abundant enough to be considered a problem, reduction of their population by fumigation could have contributed to the good results. Fumigation, by providing more plants per pound of seed, reduced the seed cost by substantial amounts, often exceeding the $300 to $400 per acre fumigation expense.

Soil fumigation with the methyl bromide-based fumigants has generally increased the size of seedling stock of Douglas-fir, western white pine, Engelmann spruce, and ponderosa pine. These effects of fumigation on the size of planting stock are, for the most part, beneficial since they have helped to reduce the time required to produce stock which is suitable for planting. A reduction of 1 year in production time is roughly equivalent to $3 to $4 per thousand seedlings or $3,000 to $4,000 per gross nursery acre. Since fumigation increases the plant density from a given amount of seed, a reduction in sowing rates is required to capitalize on the full effects of fumigation on plant size.

Survival of 2-0 stock from fumigated seedbeds when "outplanted" into semi-controlled soil-moisture-stress levels was generally equal to or better than that of stock from unfumigated soil. Douglas-fir survival under moderate and severe soil moisture stress was significantly improved by fumigation. In contrast, the survival potential of Coeur d'Alene grown 2-0 ponderosa pine was reduced by fumigation. However, fumigation has made it possible to raise suitable 1-0 ponderosa pine planting stock which survives field planting well and is probably not as severely affected by competition in the nursery beds as is the 2-year-old stock used in testing field survival of stock from the fumigation tests.

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
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